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Applicants:	E. L.E. Kluth et al.	§	Group Art Unit:	2873
Serial No.:	09/668,049	§	Examiner:	Tuyen Q. Tra
Filed:	September 21, 2000	§		
For:	Apparatus and Method for Enhancing Remote Sensor Performance and Utility	§	Atty. Dkt. No.:	SNS.0007US

Commissioner for Patents
P.O. Box 1450
Alexandria, VA 22313-1450

TRANSMITTAL OF CERTIFIED COPY

Sir:

Attached please find the certified copy of the foreign application from which priority is claimed for this case:

Country: United Kingdom
Application Number: 9902596.7
Filing Date: February 5, 1999

Respectfully submitted,

Date: September 23, 2003

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Date of Deposit: September 23, 2003
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The Patent Office

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I also certify that the attached copy of the request for grant of a Patent (Form 1/77) bears an amendment, effected by this office, following a request by the applicant and agreed to by the Comptroller-General.

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Signed AR Brewster.

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1. Your reference

SD142

2. Patent application number
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9902596.7

- 5 FEB 1999

3. Full name, address and postcode of the or of each applicant *(underline all surnames)*

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Patents ADP number *(if you know it)*

6026736002

If the applicant is a corporate body, give the country/state of its incorporation

UK

4. Title of the invention

APPARATUS & METHOD FOR PROTECTING SENSORS AND CABLES IN HOSTILE ENVIRONMENTS

5. Name of your agent *(if you have one)*

"Address for service" in the United Kingdom to which all correspondence should be sent
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Patents ADP number *(if you know it)*

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Number of earlier application	Date of filing *(day / month / year)*

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Apparatus and Method for Protecting Sensors and Cables in Hostile Environments

Sensors for measuring pressure, temperature and temperature profiles, acoustic pressure waves and vibrations, magnetic fields, electric fields and chemical composition potentially provide valuable information which can be used to characterise oil and gas reservoirs and for managing the cost effective and safe extraction of hydrocarbon reserves from oil and gas wells. Locating such sensors in appropriate positions inside oil and gas wells using conventional methods is difficult and expensive. It is common practice in the oil industry to use wirelines or slicklines to lower sensors into remote downhole positions. While this type of deployment yields valuable information, the procedures make use of expensive equipment and personnel and require that normal production is interrupted. Slickline and wireline procedures also only provide occasional information.

Alternately, it is possible to locate sensors downhole permanently, but the conventional methods for doing this makes use of specialist cables which are permanently attached to the production string and complicated mechanical packages such as side-pocket mandrels. This method of installing permanent sensors is extremely expensive and high failure rates are common. When a failure does occur then it is not possible to rectify it without major and extremely costly intervention. In general this is seen as impractical. Repairs can then only be undertaken when a well has to be worked over for other compelling reasons. Even under such conditions rectification of the fault is expensive. It is common experience that conventional pressure sensors such as quartz gauges and silicon strain gauges fail after relatively short periods when at high wellbore temperatures and pressures. For example at 135°C or higher the expected lifetimes are short. Reasons for failures are often difficult or impossible to determine, but contributions to failure include failure of the transducer itself, or of downhole electronics, cable degradation and connector contamination.

These well known shortfalls in conventional sensors have led to the development of new types of sensors which can make use of optical fibre technology. The advantages which are invariably expected from this technology include the elimination of downhole electronics.

Recently a new technique has been established for deploying sensors into remote regions of oil wells which can provide permanent monitoring and yet allow cost effective correction in the event that sensors or their associated cables fail. This technique makes use of hydraulic control lines as a highway to deliver the sensors to the remote locations. The hydraulic control lines are rugged and provide effective protection for the sensors and their cables. To date the only sensors which have been able to make use of this form of deployment have been fibre optic sensors. They can be extremely small and flexible and can benefit from equally small and flexible cables. This allows such sensors to be moved along hydraulic small bore control lines by fluid drag and to be positioned in remote locations in oil and gas wells. Water is a most convenient fluid for deploying such optical fibre sensors in hydraulic control lines since it is readily available, has excellent low viscosity for pumping and can withstand conditions of very high temperature at high pressure. However, extensive laboratory testing at SensorDynamics has established that when optical fibre sensors or optical fibre cables are exposed to water at greater than 100°C or so and simultaneously to high pressure such as 4000 psi or greater, then water causes damage to the sensors and also to the cables. It has been shown that water which is in direct contact with the silica fibres can enter into and react with the silica to create highly stressed layers inside the optical fibres and also can cause failure of the silica through etching. etch silica. In optical fibre pressure sensors, water has been shown to be directly linked to rapid drift in the zero point with time. At 150°C or greater, the zero point of un-protected fibre optic pressure sensors can change by more than 4000 psi over relatively

short time periods. Similarly extreme behaviour has been shown to occur when unprotected optical fibre Bragg gratings are exposed to water under these conditions. Optical fibres have also been shown to change dramatically in length. Changes greater than 1% have been measured.

In an effort to circumvent these undesirable effects, water has been replaced with a range of other fluids, including silicone or perfluorocarbon fluids and others, some of which are generally regarded as very inert and stable, even at temperatures above 200°C. Trials with these fluids showed that damage rates could be reduced but none of the fluids could eliminate damage entirely.

Similar trials with coated fibres showed some improvements, but in no case could a coating or combination of coatings be found which promised long term survival of optical cables, or which reduced the zero point instability of optical fibre pressure sensors to acceptable levels. The most significant improvements were found when optical fibres were coated with carbon, preferably followed by polyimide. However, even the most promising improvements were insufficient to yield a commercially attractive solution. A particular limitation which was identified appears to be associated with pin holes which are very difficult to detect and which act as centres for chemical attack that can lead to spreading damage.

This has lead to a widespread search for other coatings which can be applied to the optical fibre sensors and to cables to prevent attack by water or other molecules. Extensive laboratory testing at SensorDynamics showed that a wide range of metal coatings failed to protect sensors or cables when exposed to water at high temperatures. Nickel, copper, gold and other metals were tried. None survived tests at 250°C over the long term. All coatings were found to affect the temperature sensitivity of the pressure sensor in an undesirable way, increasing the unwanted temperature sensitivity of a sensor by greater than an order of magnitude. In every case additional complications were foreseen in protecting fusion splice joints which inevitably expose bare silica to the environment where optical fibres are spliced.

It has now been established that fibre optic sensors can be effectively packaged to provide a stable response at high temperatures and pressures when the sensors are surrounded by silicone oil. This protection can be extended so that sensors can be deployed in remote locations, including downhole locations in oil and gas wells, where the wellbore fluids can be highly corrosive.

A recent patent application by SensorDynamics teaches the use of liquid metals or other liquids in combination with a silica or elastomer capillary. Other materials may also be chosen for the capillary, for example sapphire. The use of metals or other materials which are in the liquid state under the expected operating conditions introduces a series of desirable features. Many Liquid metals readily "wet" and hence form a tight interface with silica; some liquid metals, indium, for example are reported to bond to silica. This also enables a highly reflective surface to be produced at a fibre cleaved end-face when "wetted" by a liquid metal. Liquids cannot support shear stress and therefore do not cause sensors to change their behaviour with changing temperature. Liquid metals also can readily protect splice regions as well as coated regions of optical fibres and mirrors Liquid metals can be applied relatively easily to fibres and pumped into capillaries. The use of a liquid interface between the sensor surface and the surrounding capillary further permits the use of multiple coatings on the inside and outside surfaces of the capillary without introducing temperature sensitivity effects in the sensor. In principle the capillary can be used to add protection to cables as well as to sensors.

When pressure sensors are deployed inside hydraulic control lines, referred to as sensor highways, it is necessary to ensure that the downhole well bore pressure can be communicated to the interior of the sensor highway where the sensors are located.

The ...erior of the sensor highway may be filled with a fluid. This fluid may be in the form of a liquid or gas. A useful liquid is an inert oil such as silicone based oil which can be comparatively stable at common bore hole temperatures and pressures. Silicone based fluids can be obtained commercially which are stable at 250°C and higher. The stability of these fluids varies depending on their purity. It can be difficult to guarantee the purity of such fluids over extended periods unless the fluid is enclosed in a hermetically sealed environment. When the highway fluids are allowed to be in direct contact with wellbore fluids, then diffusion and convection can occur. This can result in the ingress of water molecules and other species into the highway. In the long term this can result in a hostile environment which attacks even carefully packaged sensors.

It is therefore of great value to devise means for establishing and maintaining the fluid surrounding the sensors and cables in a condition which minimises change in sensors and cables. This is the principal aim of this invention.

When acquiring downhole pressure information, pressure communication from the well bore to the sensor inside the highway should preferably be such that as little water or wellbore fluid can enter the highway. The objective should be to minimise the possibility of foreign molecules entering the sensor and hence causing drift. Water molecules and OH groups are known to be chemically very aggressive at high temperatures and pressures and well bore fluids vary widely in composition, from well to well and in time. These fluids can be extremely aggressive chemically.

An approach which reduces or eliminates the ingress of molecules from wellbore into the region where the sensor is located is to interpose a membrane or diaphragm. This approach brings with it a number of disadvantages which can lead to difficulties in acquiring pressure information accurately. For example, the diaphragm or membrane have to respond to small changes in pressure, yet the direct contact with the wellbore fluid can result in corrosion or in the scale formation which change the response of the membrane or diaphragm to pressure changes. It is also difficult to create a mechanical arrangement which can have the dynamic range required to cover the large pressure surges which can occur in oil and gas wells.

An alternative approach is to allow a direct connection between the wellbore fluid and the interior of the sensor highway, in such a manner that the wellbore fluid is prevented as much as possible from causing undesirable changes in the sensors or cables while allowing the relevant information to be acquired by the sensors.

For example, the wellbore pressure may be communicated accurately to the sensor through an intermediate liquid. The intermediate liquid may be selected so that long term exposure results in minimal change in the sensor. It is also important that the intermediate liquid can be easily replaced if contamination or degradation occurs in particularly hostile environments.

In another example, when the composition of the wellbore fluid is to be analysed, the composition sensor probe must be in direct contact with the wellbore fluid. It is preferable that direct contact between wellbore fluid and sensor probe is restricted to the time when the measurement takes place and that otherwise the sensor probe is in an environment which does not change or degrade the sensor or cable. For example, when a fibre optic fluorescence probe is used to ascertain aspects of the chemical composition of the wellbore fluid, the end of the fibre optic probe should be directly immersed in the wellbore fluid. If this direct contact is maintained permanently then it is likely that the optical fibre will suffer damage. On the other hand, the useful life of the probe is extended if direct contact is only occasional and if the probe is surrounded by an inert fluid at all other times.

We describe two examples of how sensors and cables can be protected against damage when the sensors are used in oil wells. The examples are intended to be entirely non-limiting. One example treats the case of an over-pressure well, while the other treats the case of an under-pressure well.

An over-pressure well has a downhole pressure which is higher than the pressure exerted by a highway which is entirely filled with fluid. That is, if the highway were to be opened to atmospheric pressure at the wellhead, then fluid will be forced to flow upward in the highway. When the highway is sealed at the upper end, the fluid at the uppermost point will be at a positive pressure. This over-pressure condition applies typically to oil wells during their early stages of production when the hydrocarbon reservoir pressure is at its highest. If the fluid inside the highway is a liquid which has been carefully de-gassed, then this fluid column of fluid has a high bulk modulus and therefore compresses very little under hydrostatic pressure. Under these conditions a surge in the downhole well pressure, which can occur when the flow rate of the well is decreased or shut off, will not cause significant amounts of well bore fluid to enter the highway.
In this case, pressure from the well bore may be communicated simply to the sensor inside of the highway by a length of tubing connecting the well bore to the highway. This tubing may be filled with a liquid metal or another fluid whose composition is such that it causes minimum change in the sensor over the long term. The liquid metal or other fluid should also not mix readily with the constituents of the well bore fluid. The purpose of this liquid metal or other liquid is to form a barrier to molecules from the well bore fluid and to prevent these from entering the highway and reaching the sensor.
The pressure communicating tubing which enables direct contact between the hydrocarbon reservoir fluid and the highway fluid should preferably be arranged so that the well bore fluid contacts the liquid metal from above to prevent gas from rising from the wellbore, through the liquid metal column. This may be achieved by forming the connecting tubing into an elbow, with the wellbore end of the column pointing upward.

Figure 1 shows a schematic view of an oil or gas well, fitted with a highway for deploying and retrieving sensors and carrying out permanent downhole measurements, including the measurement of downhole pressure. Figure 1 shows a production tubing string 11, surrounded by a casing string 12, a perforated section of the casing 13, to allow the inflow of hydrocarbon fluids 14 from the hydrocarbon reservoir into the well. The well is completed by a wellhead 15 which includes valves 16 for shutting the well in. A packer 17, to prevent the upper region of the annulus between the production tubing and the casing from being directly connected to the well bore pressure. The packer is shown with a high pressure penetrator 18 which allows the hydraulic control lines 19, which constitute part of the sensor highway, to pass through the packer. Typically the control lines are ¼ inch in diameter and are made of stainless steel. It can be convenient to coil the control lines around the production string at one or more regions along that string. The control lines are often secured to the production string by clamps 110, which also serve to protect the control lines from damage during installation. The sensor highway is shown exiting the wellhead through high pressure seals 111, past valves 112 which serve as emergency pressure seal and then through high pressure feed-through devices 113 where the fibre optic cables emerge while maintaining a pressure seal between the ambient surface environment and the interior of the sensor highway. The sensor highway contains optical fibre cables and attached sensors. The sensors can include pressure sensors, distributed temperature sensors, acoustic sensors, electric and magnetic field sensors composition sensors and others. The sensors or their associated cables need not necessarily be fibre optic types. The cable itself may also not connect to a sensor at all but instead be used as a means of communication to an optical switch used to control downhole valves and machinery remotely. It is advantageous that the cables and sensors should be capable of being located to the remote locations by fluid flow and they benefit from being retrievable and replaceable. In the same figure 1 the sensor

highway is shown to turn around at a point below the packer. The return leg of the highway shown in Figure 1 includes a flow control element 115 located above the packer for example only. This device 115 is intended to have two states, one of which can prevent flow of fluid in the upward direction or reduce flow to a reduced and acceptable rate. When the device is in the second state, fluid can flow freely in both directions Switching between the two states can be achieved, for example, by a separate control line from the wellhead. It may be preferable to have a similar device included in both legs of the highway.

Near the turn-around point 124, is shown a connection116 to another section of control line which is shown to contain a flow control element 117 and which continues along the production string. Sensors which are deployed by use of the highway generally are prevented from entering the continuation of the control line beyond the turn-around region leading to the hydrocarbon reservoir. A distributed temperature sensor, such as may be used in conjunction with a York Sensors LTD DTS 80, may be deployed in a single ended mode where the end of the sensor cable will be inside the highway , or in a double ended mode, where the sensor enters the highway in one leg and emerges at the surface from the other leg of the highway. Generally other sensors such as pressure, acoustic, electric field and composition sensors operate in reflection mode and hence enter the down-leg of the highway during deployment, but only emerge from the other end of the highway when they need to be retrieved from the highway. For example, a typical polarimetric pressure sensor as has been described by SensorDynamics, and its associated cable would enter the highway at the high pressure seal and the sensing part of the assembly would be located near the turn-around point of the highway, either in the down leg or in the up leg. The wellbore pressure at location 121is communicated along the liquid pathway which starts at 121, connects to the barrier fluid reservoir at connection 123 and passes through the barrier fluids 121 and 122 inside the chamber 118, exits via connection119 and continues through control line via connection 116 to the pressure transducer114. In general it is preferable to have the end of the sensor and cable assembly pass the turn around point. This has the advantage that if fluid enters the highway from the hydrocarbon reservoir side of the highway, then the fluid flow will not cause the pressure sensor to change its position significantly This will also be advantageous in the event that gas enters the highway. In this configuration, gas will be unable to enter the sensor capillary packaging and fluid barrier. Such a change in position could result in a change in the pressure reading.

It should be understood that although in Figure 1 the highway for deploying sensors is shown as a return control line, located in the annulus between the production string and the casing, this should be regarded as one example only. SensorDynamics has demonstrated in field trials examples of highways which have been located both inside and outside the casing. In certain situations it may be preferable to locate the highway path inside the casing; in other situations it may be convenient or necessary to locate sensors outside the casing. In yet other situations a mixture of both pathways may be preferred. It should also be understood that the wall of the casing can be used for creating a highway path for the sensors and their cables. Equally, the highway path can make use of the interior of the production string or possibly the wall of the production string for all or part of the highway circuit.

Modern drilling and completion techniques introduce other possible configurations for sensor highways to collect information from remote points in the hydrocarbon reservoir or near-by formations. As the techniques develop for real-time reservoir management, the need to have more direct information in locations inside the reservoir will increase. The sensor highway can make use of smallbore coiled tubing pathways into the regions of the reservoir away from the production or injection wells. These coiled tubing lances can be used to collect a range of information including reservoir pressure, unaffected by the wellbore effects, acoustic information, without high level interference from a producing well, composition information beyond the well' producing zone and others.

The flow control elements 115 and 117 which are shown in Figure 1 may not be required when dealing with oil wells whose downhole pressure exceeds the pressure exerted by a highway which is entirely filled with a fluid. In the over-pressure well example there is very little transfer of fluid from the hydrocarbon reservoir into the highway in the event of a pressure surge during a well shut-in. Hence the fluids 121 and 122 remain fully effective as a barrier between the highway fluid and the hydrocarbon reservoir fluid. In such over-pressure wells the use of the barrier fluid reservoir may also be eliminated or simplified. For example it might be replaced by a section of control line containing sufficient barrier fluid to compensate for expansion of the highway during a well shut-in.

As production of oil and gas proceeds over a period of time and the wells reach a state where the downhole pressure drops and becomes less than the pressure from liquid filled highway, the importance of control of fluid transfer to and from the highway via control elements 115 and 117 becomes important as does the barrier fluid reservoir 118.

During the well shut-in, if there is a decrease in the well bore pressure, as happens when the flow of the well is re-started, then fluid flow should be allowed from the highway into the barrier fluid reservoir 118 - so that the sensor measures the bore hole pressure and not the pressure exerted by the column of fluid in the highway - which will be higher than the bore hole pressure if fluid is not allowed to drain from the highway. This return flow rate is preferably high enough so that the pressure at the sensor remains representative of the instantaneous well bore pressure and is not dominated by the pressure caused by the weight of an unbalanced column of fluid in the highway above the sensor.

A second example treats the case of the under-pressure well. As fluids are extracted from the hydrocarbon reservoir, the operating downhole pressure well decreases, the height of fluid column which is sustained in the highway will also drop. It is to be expected that the downhole pressure during normal production will reach a point where the highway fluid will drop to a level below the uppermost point in the highway, leaving a section of highway control line which does not contain liquid. In the event of a well being temporarily shut in, the resulting transient in downhole pressure will tend to push fluid into the highway until the weight of the column balances the downhole pressure. It is preferable to minimise the amount of fluid which has to be transferred into the highway to equalise the pressure during a well shut down. This minimises the required volume of the fluid reservoir between the highway and the well bore fluid. Minimising the flow will also minimise the error in the sensor reading due to pressure drops between the sensor and the well bore. In general it is desirable to have a fluid pathway between hydrocarbon reservoir and sensing location which ha a low impedance to fluid flow. Hence, connections from point 121 into the barrier reservoir 118 and between 119 and the sensing locaton114 are preferably as short as convenient and of as large a bore as is practical.

Where a number of sensor cables occupy space inside the highway, it can prove difficult to achieve a perfect seal around the multiple cables. Provided the flow rate through this seal is sufficiently low so that the height of the liquid column does not seriously degrade the measurement of the downhole pressure such leakage can be acceptable. In Figure 2 we show by non-limiting example a configuration of the flow limiter (115 in figure 1) which preferably includes a reservoir in the space above the sealing or choking element to minimise the change in level inside the highway during a negative pressure surge in the well bore due to imperfect sealing around the sensors or sensor cables inside the highway. That is, when the flow in the well is re-started following a period of shut-in, or when the well flow is simply increased, the pressure in the well bore will decrease and will eventually cause the level of liquid inside the highway to decrease.

Figure 2 describes a non-limiting example of the flow control element 115 in Figure 1. It should be clear that such flow control elements may be installed in one or both legs of the highway and also that the precise location along the highway can include locations above the packer as well as below the packer. In figure 2, one or more fibre sensors or cables 21 are shown located inside the highway 22. The highway control line continues into a container 23. Inside this container the highway control line is shown to be perforated so that fluid can readily enter the main volume of the container 23, while encouraging sensors and their cables to be guided along the highway. Container 23 is shown to contain highway fluid 25 in the lower section of the container. Preferably this level can be established by control from the surface, before flow from the well is re-established. The purpose of the container is to reduce the change in fluid level in the highway for a given flow rate past the sealing or choking element and thereby minimise errors in the pressure measured at the sensing point. While the level of fluid is inside the volume 25, a small leakage past the seal or choke causes a much reduced change in the column pressure.

It should be noted that the pressure at the sensing point in the well bore is at its highest when the well is stopped. At this stage the highway fluid may be forced down to a level which is near the bottom of container 23 by using, for example pressurised nitrogen gas at the surface. The seal or choke is then closed and the nitrogen gas pressure is released. The use of the term choke in this context is meant to indicate a significant reduction in flow past the device, rather than an ability to control the flow rate continuously between maximum and minimum rates. The column of liquid in the highway then will be under positive pressure from the well bore. (That is, if the choke element were to be opened, the wellbore pressure would cause liquid to flow in the upward direction and reach a level above the choking element before the pressure exerted by the fluid column balances the wellbore pressure.) For the purposes of monitoring the dynamics of the wellbore pressure accurately it is preferable to have the choke element closed and where a fluid reservoir 23 is included, to have this reservoir at least partielly flilled with highway fluid. The sensor reads the well bore pressure under these conditions. As flow is re-started in the well, the pressure in the well bore will drop, but it will remain greater than the pressure from the fluid in the highway provided the seal or choke is positioned low enough in the highway. The highway control line 26 is shown to connect to the sealing or choking device 27 which contains a remotely controllable seal or choke 28 and to continue as section 210 Control of the seal or choke is indicated to be effected by arrow 29 . Different methods may be used to effect control. One method is to have an independent hydraulic control line leading from the well head to sealing or choking device 27. Another method may be preferred, particularly when the cost of the independent control line is excessive. One such other method is to have a feed-forward connection from a point above the seal or choke to the control input 29. In this way the seal or choke may be set from the surface without an independent control line.

The arrangement shown in Figure 2 serves to minimise or reduce the amount of fluid which flows up the highway in the event of a positive pressure transient in the well bore and also to eliminate or reduce to an acceptable value the errors which can arise at the sensor in the event of a negative pressure surge in the well bore.

An alternative approach to the flow control device in Figure 2 is to eliminate the reservoir 24, but to retain the sealing device 27 and to make use of the barrier fluid reservoir 118 in Figure 1. During normal operations the sealing or choking elements will be set closed. In the event of the well being shut in, the wellbore pressure will increase. The sealing device 27 will prevent movement of fluid into the highway. After the positive pressure transient information has been acquired, the fluid in one leg of the highway can be expelled to the surface by application of over pressure nitrogen or another gas to one of the legs of the highway while opening the other entry point at the surface. The surface entry points are closed. The liquid will then settle to the lower sections of the two highway legs. At this time the seals or chokes

27 may be closed. (An alternative method which may be preferred to displace the deployment fluid inside the highway is to use another liquid which has the property that it changes to the gas phase at the wellbore temperature. Under these conditions barrier fluid will be sucked upward into the highway if the highway is opened to ambient pressure at the wellhead. This method may be preferred where it is desirable to surround the sensor and sensor cable by barrier fluid, in order to minimise degradation of sensors and cables in high temperature regions. The gas in the region above the barrier fluid may preferably be chosen to be an inert gas such as nitrogen for example.) The gas in the highway above the seals is then allowed to come to ambient atmospheric temporarily to allow the gas pressure to equilibrate approximately. At this stage the wellbore pressure is at its highest and will be greater than the pressure exerted by the fluid column in the highway. The well flow can now be re-started and will cause the well bore pressure to decrease. This decrease will be accurately recorded by the downhole sensor at position 114 in Figure 1. As long as the well bore pressure exceeds the pressure exerted by the weight of the liquid column in the highway. This condition is assured by suitable choice of level for the flow control devices 115 in Figure 1 or device 27 in Figure 2. However, for a low pressure well or a heavily depleted well where the pressure has fallen to a low level of say 1000psi, this suitable choice of level for the flow control device may actually be very deep into the oil well close to production . For example, the maximum height ,h, of fluid of density ρ, between the choke and point of well production (32 in figure 1) , allowed so that the well pressure is greater than that due to the column of fluid (equal to ρgh where g is the gravitational constant) may actually be quite small (of the order of a few hundred metres). Furthermore, this level will depend very much on the density of the chosen highway fluid which could be significant if a liquid metal were to be used. The deep positioning of the flow device will affect the operational specifications significantly as the temperature and pressure (in the early days of the well production) can both be extreme (temperatures up to 350C in some steam flood wells). A deeply positioned flow device will also require a deep reaching additional hydraulic control line if this were to be the chosen method of flow device control. Note, however that if these extreme conditions do not prove to be a problem, then the positioning of the flow devices as close as possible to (but still above) the sensor regions of the fibre could be of benefit . This would make it possible to operate with the majority of the highway empty (or flushed with dry nitrogen gas) and require that only a small region of the highway be filled with hydraulic, unreactive, low water content fluid (for example a silicone oil or a liquid metal). The majority of the down lead cable would be subject to high temperatures but in dry nitrogen gas, an environment which which has little impact on the cable. This design would reduce the required volumes of barrier fluid in the highway.

Because oil and gas wells have to function over long periods, it is also desirable that such devices are equally long-lived, or that they can be retrieved and replaced simply, without demanding the shut-down of normal well production. Deployable valves which are capable of sealing around fibre cables and which can be pumped along the highway and seated in appropriate locations have been the subject of patent applications by SensorDynamics.

It should also be evident that an independent pressure sensor may be placed into the highway to sense the position of the liquid in the highway. Preferably this pressure sensor is as far from the position 114 which is chosen to monitor the wellbore pressure. The optimum point for this is immediately below the lowest equilibrium liquid level which can be expected during the life of the hydrocarbon reservoir. In an under-pressure well, this sensor will register the pressure due to the column of liquid above it. This information can be used to model the effect of fluid flow in the highway and to improve the data acquired by the primary pressure sensor which is located near the well bore at position 114 in Figure 1.

The device117 which controls the flow of fluid between the barrier fluid reservoir and the sensor highway control lines 19 in Figure 1 should preferably include the following features: While the sensors

are being deployed, the fluid flow from the highway into the barrier fluid reservoir should be kept to a low rate so that the flow in both legs of the highway is sufficient to move the sensors and cables. One solution which is given as a non-limiting example only, is to have a valve which allows downward flow from the highway up to a critical flow rate, at which time the valve closes to reduce or stop flow. This can be achieved by over-pressure from the surface at the start of any deployment operation.

When the well which has been flowing is shut in and the well pressure rises, the impedance for fluid transfer from the barrier fluid reservoir into the highway should be low in the region between the barrier fluid reservoir and the position of the pressure sensor, so that the pressure at the sensor is representative of the well bore pressure and does not become dominated by pressure drops between the pressure communicating point 121 and the sensor location 114. The impedance will be reduced by choosing as large a bore for the fluid path as is practical. Preferably, the flow control unit 117 should be capable of replacement if it becomes sticky or damaged. (this is the subject of a prior patent application by SensorDynamics.)

With reference to Figure 3we describe a non-limiting example of barrier fluid assembly. The highway which contains the pressure sensor and possibly other sensors 31 connects to a first barrier fluid reservoir section at connection 33. This reservoir is shown to contain a first barrier fluid 34 and a second barrier fluid 35. The connection may contain a flow control device 32. The first barrier fluid reservoir section connects to a second barrier fluid reservoir section at connector 38. The second barrier fluid reservoir contains the second barrier fluid 35 and may also contain fluid 37 which is the same hydrocarbon fluid as the well bore fluid 37. Barrier fluid 34 is of a lower density than barrier fluid 35 and the two fluids are preferably highly non-miscible. Fluid 35 may be chosen to be a fluid such as an indium based alloy which is in the liquid state at the well bore temperature and which has a low propensity to react chemically with the hydrocarbon well bore fluids. Preferably fluid 35 also minimises the diffusion of molecular species of the well bore fluid. It should be recognised that a single barrier fluid may be sufficient in wells where the well bore fluid is sufficiently benign chemically. Equally it is possible to realise a design which includes a single reservoir container even if two barrier fluids or more are used, provided that the relative densities are such that the ordering of fluids according to the densities achieves the objectives.

It is also to be noted that should either barrier fluid 34 or fluid 35 become contaminated or degraded, then it is possible to displace these into the well bore and to replace the fluids with new fluids without requiring the well to be shut in. This can be achieved for example, by injecting fluids 34 or 35 at the well head through the hydraulic control line. If the ambient well surface temperature is below the melting points of either fluids, then these materials may be injected in the form of small pellets. These pellets will change to liquid at a depth where the well temperature exceeds the melting point of the pellet material.

Barrier fluid 34 is preferably a liquid metal such as gallium or other metal which is in the liquid state at the well bore temperature, which is of lower density than fluid 35 and which does not tend to mix with fluid 35. This fluid 34 may also be a non metallic fluid which is inert with respect to fluid 35 and with respect to the pressure sensor or its package. The first barrier fluid 34 is also preferably chosen to have a low viscosity so that it can flow with low resistance within the highway control line 31 and thereby minimises errors in the pressure measurements by the pressure sensor due to flow induced pressure gradients between pressure communication point 31 and the position of the pressure sensor.

It will also be clear to those skilled in the art that alternative configurations can be devised which achieve the objectives of the apparatus shown in Figure 3 in which mechanical means may be employed.

It should also be noted that the multiple barrier fluid configuration of figure 3 could also be achieved with an annular vessel similar to that shown (inset) in figure 1. The choice of either configuration would depend upon ease of fabrication and incorporation into a particular well.

In Figure 4 we show the control line highway 41containing one or more sensors connected into a barrier fluid reservoir 43 via a section of control line which may include a flow control device 42. The hydrocarbon reservoir fluid 45 is allowed direct access to the interior of the barrier fluid reservoir at point 46 and may enter the chamber 43. In the barrier fluid container 43 is shown fluid 44 which acts as a fluid barrier between well bore fluid 45 and the sensor and its package. It is to be realised that a further fluid may be in the highway in the region where the sensor is located or above it. A mechanical piston 47 is shown separating the fluids 44 and 45. This piston may contain a small bore connection 48 which may be filled with fluid 44. The piston assembly communicates the pressure of the well bore to the interior of the highway. When conditions are such that a large movement of liquid is required to move into or out of the highway, then the piston position will be adjusted in response to the existing pressure difference. Small errors can be introduced by stiction in the piston, but these will constitute a small part of the total change. When very small changes in pressure occur then the it is preferable to have a direct fluid to fluid contact since stiction in the mechanical piston may hide such change or introduce errors which are large in relation to the change which is to be measured. Such small pressure changes commonly occur in well tests after the initial large transient. These signals contain important information about the hydrocarbon reservoir and are of great interest to reservoir engineers. The fluid to fluid contact will circumvent this shortcoming and therefore allow very small pressure changes in the well bore to be measured accurately by the sensor in the highway. On the other hand the small bore fluid connection 48, on its own, will not be able to respond to large pressure changes without causing significant errors to occur over a period required for the fluid transfer to take place.

The mechanical piston may be designed to be replaced by wireline or slickline intervention or by use of a robotic vehicle.

We Claim:

1. Apparatus for protecting sensors and sensor cables which includes a liquid reservoir containing one or more liquids which form a barrier against ingress of foreign molecules from the environment whose physical or chemical characteristics are to be monitored.

2. Apparatus as in claim 1 where liquids in the barrier fluid reservoir may be replaced without removing apparatus.

3. Apparatus as in claim 1 or claim 2 where fluid from the barrier fluid reservoir can be moved under remote control to surround the sensors and part or all of the cables.

4. Apparatus as in claim 1 or claim 2 and including one or more devices for reducing or preventing movement of fluid between barrier fluid reservoir and sensor highway control line when pressure surges occur in the environment whose pressure is to be monitored.

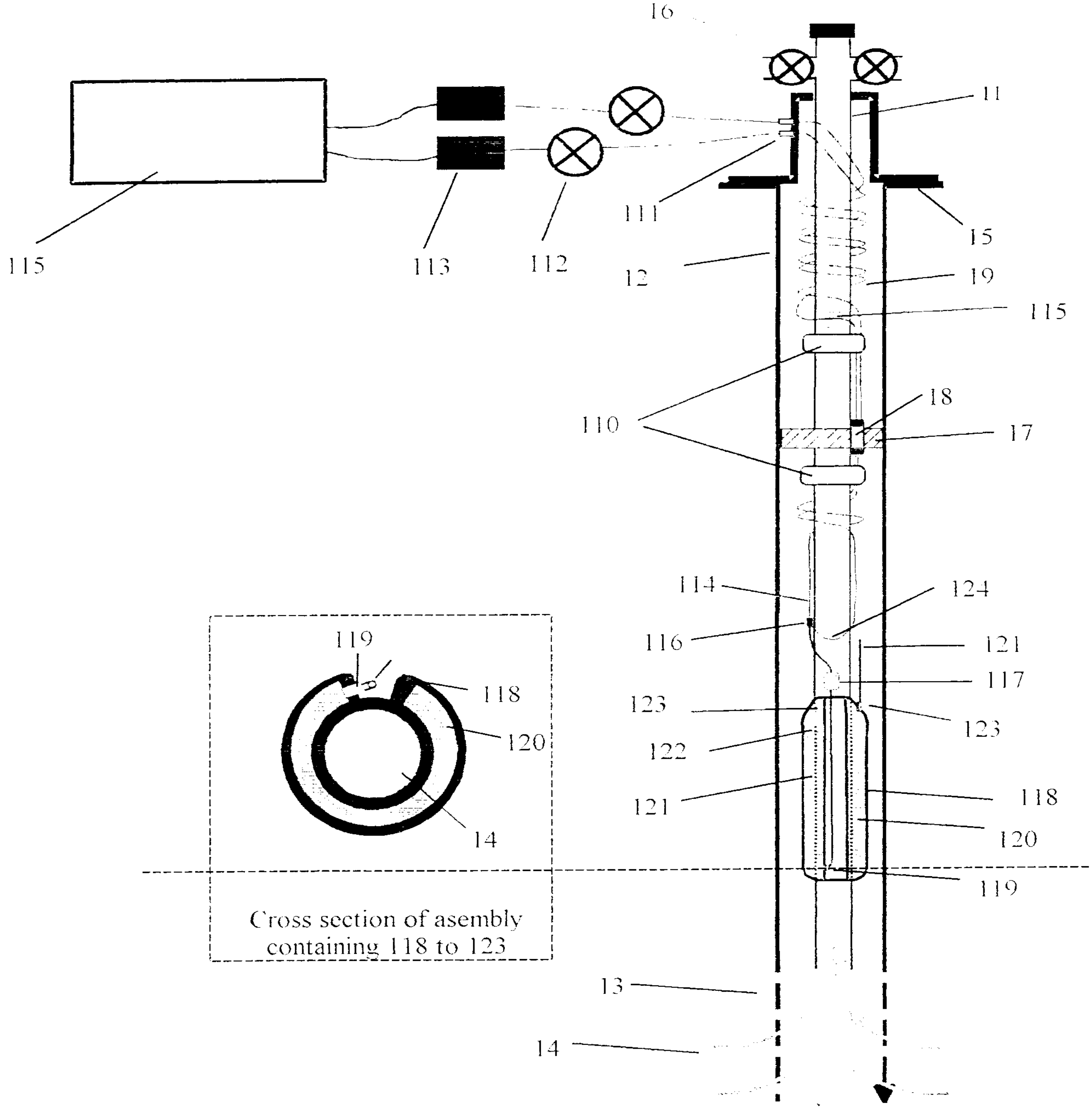
5. Apparatus as in claim 1 or in claim 2 where the barrier fluid reservoir consists of more than one sections.

6.

7. A pressure sensor which includes one or more liquids forming a barrier against ingress of foreign molecules from the fluid whose pressure is to be measured.

8. A pressure sensor as per claim 2 where the barrier can be replaced in situ without removing the sensor.

9. An oil or gas well containing apparatus for deploying sensors and cables by use of fluid drag which contains apparatus as claimed in any or all of the preceding claims.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Cross section of asembly
containing 118 to 123
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Figure 1

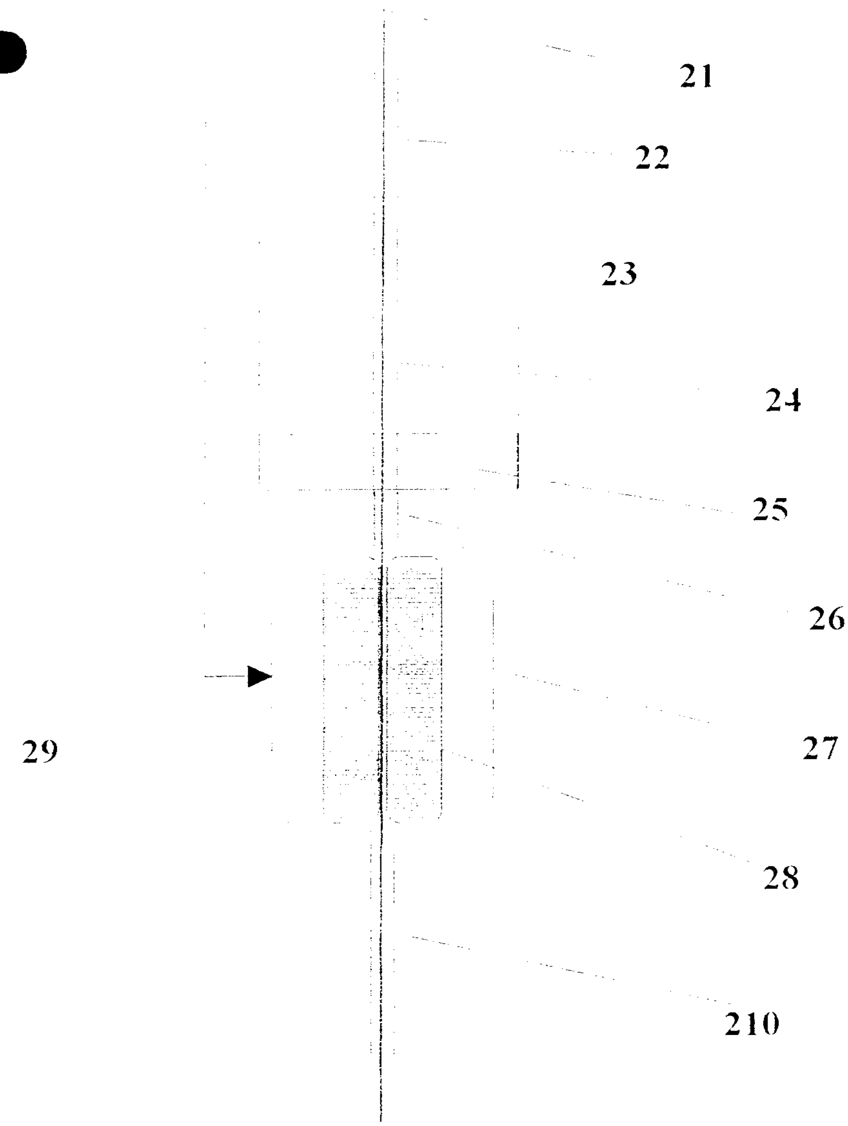

Figure 2

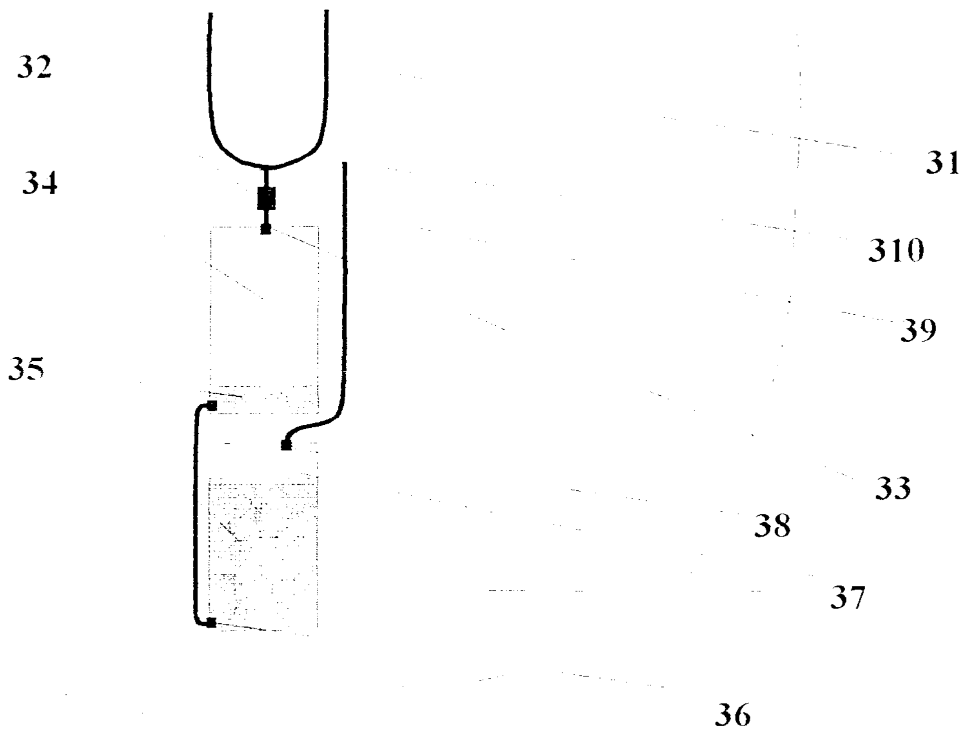

Figure 3.

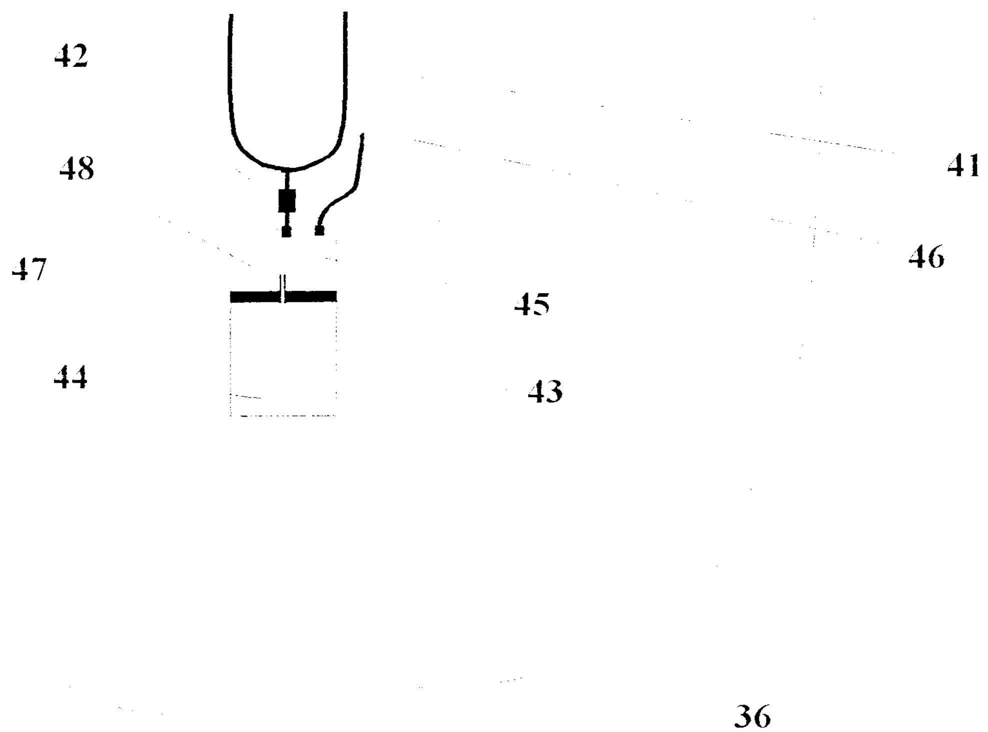

Figure 4.